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Land Use and Land Cover Change in Sagarmatha National Park, a World Heritage Site in the Himalayas of Eastern Nepal

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Land use and land cover (LULC) changes that occurred during 1992–2011 in Sagarmatha National Park, a United Nations Educational, Scientific, and Cultural Organization World Heritage Site in the Himalayas of eastern Nepal, were evaluated using multitemporal satellite imagery in combination with land use data and sociological information gathered from semistructured interviews and workshops. We asked study participants about LULC changes, the causes of each change, and the likely duration of its effects, and used this information to produce high-resolution maps of local perceptions of LULC change. Satellite image analysis revealed that above 6000 m there has been a decrease in the area covered by snow and ice and a consequent expansion of glacial lakes and areas covered by rock and soil. Between 3000 and 6000 m, forest and farmland are decreasing, and areas under grazing, settlement, and shrubland are increasing. Such LULC changes within the protected area clearly indicate the prevailing danger of land degradation. Results from the interviews and workshops suggest that people tended to detect LULC change that was acute and direct, but were less aware of slower changes that could be identified by satellite imagery analysis. Most study participants said that land use changes were a result of rapid economic development and the consequent pressure on natural resources, especially in the tourism industry and especially below 6000 m elevation, as well as limitations to protected area management and a period of civil war. Human influence coupled with climate change may explain the changes at higher elevations, whereas anthropogenic activities are solely responsible in lower areas. Although global factors cannot be mitigated locally, many of the local drivers of LULC change could be addressed with improved management practices that aid local conservation and development in this high mountain ecosystem. A broader interdisciplinary approach to LULC change should include a mix of satellite image analysis and local observations.

Keywords: *Sagarmatha National Park; UNESCO World Heritage Site; land use; land cover; satellite imagery; perceptions.*

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Introduction

Land use and land cover (LULC) change is one of the most important forms of environmental change occurring in many of the world's mountain regions (Körner and Ohsawa 2005). *Land use* refers to human activity on a piece of land, and *land cover* refers to its surface features (eg Lambin and Meyfroidt 2010). Recent small-scale analyses have highlighted LULC change in the Himalayas (eg overexploitation, fragmentation, and degradation; Chaudhary et al 2007). LULC change is of increasing concern with regard to national and global policies promoting sustainable mountain development (eg Kohler et al 2012). Policy-makers seek information on the root causes of LULC change in order to develop clearer polices and management guidelines that focus on causes, not symptoms. However, processes that drive LULC change in mountain regions are complex, occurring at various temporal and spatial scales, with interlinked environmental, social, and economic impacts, and they require multiple methods of analysis to understand the drivers and their impact on the environment, landscapes, and rural societies (eg Lambin and Meyfroidt 2010).

As in other parts of the Himalayan region, traditional resource use in Sagarmatha National Park and Buffer Zone (SNPBZ) has changed rapidly since the mid-1970s in response to a range of interacting institutional, economic, political, cultural, climatic, and demographic processes (eg

Stevens 2013). Recent research using remote sensing data has focused on land cover change in SNPBZ (eg Bajracharya et al 2010), recognizing the complexity of many key assumptions about deforestation (eg Ives 2004). The area's glaciers have also received extensive spatial analysis (eg Thakuri et al 2013). However, there has been very little spatially explicit research on the ways that changing land-use strategies contribute to LULC change and vice versa (eg Lambin and Meyfroidt 2010). In this respect, social sciences are especially well placed to collect the fine-grained qualitative and quantitative information that is needed for a local-level analysis of LULC change (eg Vedwan and Rhoades 2001; Couzin 2007; Jurt et al 2015).

Although remote sensing has been increasingly recognized as an essential tool for studying LULC change, spatial analysis alone may miss the underlying driving processes, unless combined with field studies at very fine scales (eg Lambin and Meyfroidt 2010). In particular, a narrative perspective grounded in the experiences and concerns of residents is important in understanding linkages between standard categories of driving forces and outcomes observed in patterns of LULC change and in targeting management efforts (eg Kennedy et al 2009; Lambin and Meyfroidt 2011). This study examined LULC change trajectories and change rates in SNPBZ from 1992–2011, and examined how local people perceived LULC change, particularly its drivers and temporal effects, using ethnographic and geospatial methods. As a result, this paper presents locally and finely contextualized knowledge developed by small mountain communities, which is important for interpreting LULC change trajectories and for developing local management approaches to decision-making as envisaged by the changing concept of United Nations Educational, Scientific, and Cultural Organization (UNESCO) World Heritage Site designation (Conradin and Wiesmann 2014). The conclusions drawn here will be helpful for planners engaged in protected area policy and resource management, not only in SNPBZ but also in similar areas.

Study area

Sagarmatha National Park (Figure 1) is in the Solu Khumbu (also known as the Khumbu) district of northeastern Nepal. Sagarmatha National Park covers 1141 km^2 and was designated a UNESCO World Heritage Site in 1979. In 2002, the 275-km^2 Pharak region to the south was declared as the park's buffer zone. Most of SNPBZ lies at elevations of 4000–5000 m (31%) or 5000–6000 m (52%). In general, the steep slopes of the region below 6000 m are left as forest and grassland, whereas areas with relatively gentle slopes are extensively cultivated. The human population has increased, especially since the mid-1970s; it rose from 3465 in 1991 to 5750 in 2011, with an annual population growth rate of 2.87% (*Supplemental material*, Tables S1, S2: http://dx.doi.org/10.1659/MRD-JOURNAL-D-15-00005.S1). SNPBZ is administered by 3 village development committees—Namche, Khumjung, and Chaurikharka (Figure 1)—which function as administrative institutions for interacting with national institutions in Nepal, thus creating an element of local control and responsibility in development. Tourism has become increasingly important for local development; the number of lodges grew from 56 in 1989 to over 300 in 2012 (Gehrig 2013). Figure 2 outlines this and other major developments in SNPBZ since about 1950, along with changing land use strategies. (See Garrard et al 2012a, 2012b, for a more comprehensive site description.)

Methods

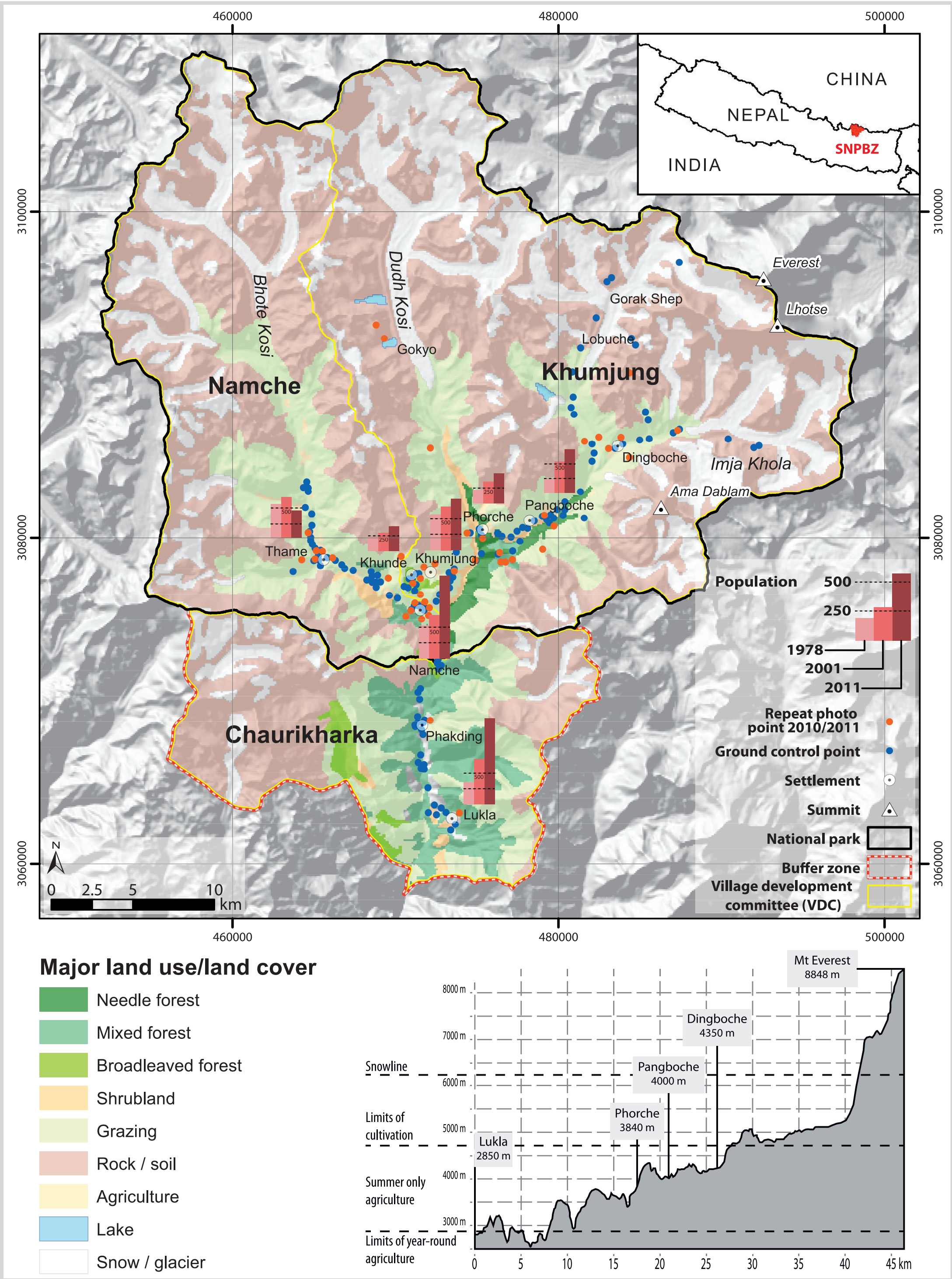
LULC change classification, analysis, and accuracy assessment

For the assessment and description of LULC change patterns, we used existing LULC maps based on Landsat Thematic Mapper, Enhanced Thematic Mapper Plus, Advanced Spaceborne Thermal Emission Reflection Radiometer images, and topographical maps. These maps were generated by the International Centre for Integrated Mountain Development (ICIMOD) and the Department of National Parks and Wildlife Conservation (DNPWC) as part of the Land Resources Mapping Project (LRMP) using 2 different classification schemes (summarized in the *Supplemental material*, Table S3: http://dx.doi.org/10.1659/MRD-JOURNAL-D-15-00005.S1). ICIMOD used object-based image analysis, whereas the DNPWC used pixel-based classification obtained via a nationwide mapping project (LRMP 1986). None of the DNPWC maps had been field verified. The ICIMOD maps had not been extensively field verified either, and areas where classification had failed had been filled with adjacent land cover categories, leading to reduced accuracy.

Therefore, step 1 was to improve and field verify all LULC classifications, using a series of very-high-resolution satellite data and 225 ground control points representing all the LULC classes present in SNPBZ. The ground control points, collected in September and October 2010, were used to ground reference all LULC classification maps. (For an overview of the LULC change classifications used and the satellite data, see the *Supplemental material*, Tables S3, S4: http://dx.doi.org/10.1659/MRD-JOURNAL-D-15-00005.S1).

Step 2 was to improve LULC change classification analysis. A variety of satellite data from different years and seasons were used (*Supplemental material*, Table S4: http://dx.doi.org/10.1659/MRD-JOURNAL-D-15-00005.S1). Scene selection for SNPBZ is difficult owing to cloud cover, so data sets were selected at irregular intervals during late autumn and winter. An Advanced Spaceborne Thermal Emission and Reflection Radiometer data set consisting of 3 bands (green, red, and near-infrared) with a geometric

FIGURE 1 SNPBZ. (Map by Elias Hodel and Rodney Garrard; land use data from DNPWC. Kathmandu)



resolution of 15 m, 4 "×" IKONOS data sets consisting of 4 bands (blue, green, red, near-infrared) with a geometric resolution of 4 m, and a RapidEye data set consisting of 5 bands (blue, green, red, red edge, and near-infrared) with a geometric resolution of 5 m were used for the visual verification and improvement of the classification maps.

LULC change classification analysis resulted in quantification of absolute changes in the spatial

FIGURE 2 Developments in the Khumbu since the 1950s (adapted from Nüsser and Gerwin 2008).

	Local livelihood and LULC dynamics	Administrative changes	Infrastructure development	Historical events and political changes
1950	Sherpa have monopoly on trans-Himalayan trade; also practice subsistence agriculture Chinese invasion of Tibet, 1950; strong restrictions on cross-border trade; eventual complete cessation of trans-Himalayan trade	Under the advice of forestry experts from the UN FAO, Nepal's government nationalized forests throughout Nepal (Forests Act of 1968), replacing traditional local land and forest management systems.	Lukla Airstrip built, 1964. The airstrip was built to facilitate the transportation of building materials for building a hospital and schools in the Khumbu. The airstrip also greatly facilitated tourists` access to the region.	Overthrow of Nepal's Rana dynasty, 1951 First ascent of Mount Everest, 1953 Nepal's King Mahendra Shah dissolved Nepal's democratic parliamentary system and instituted a 'partyless' government system referred to as the *panchayat* land system throughout Nepal, effectively ending centuries of political autonomy in the Khumbu.
1970	Emergence of tourism; 300 trekkers visit the region Establishment of cash economy; agricultural diversification, including intensive cash cropping Sagarmatha National Park tightly regulates forest use by locals and visitors 10,000+ trekkers visit the region	The Khumbu region was gazetted by Nepal's government and designated to be the Sagarmatha National Park, in 1976 Differential appropriation of natural resources and territory	First school and hospital built, 1973 First lodge built, 1973 56 lodges in Sagarmatha National Park, 1989	UNESCO declared Sagarmatha National Park a World Heritage Site, 1979; A new constitution placed sovereignty with the people instead of the king. At the local level the *panchayat* village-based forest councils replaced by village development committees
1990	Continued diversification of economic activities; outsourcing of agricultural labor; changes in herd numbers; emigration and immigration	The Sagarmatha National Park warden established local forest management committees, 1990, which gave Khumbu village officials more authority over administering forest use in the Khumbu.	A large Austrian-funded 600-kilowatt hydroelectric scheme, 1994. The hydroelectric plant introduced electricity to 5 of the 8 main Khumbu villages, including about a third of the then 125 lodges. Lukla Airstrip expanded and upgraded, 1996	Nepal's government initiated a tourism promotion program called 'Visit Nepal 1998'. The program was aimed at increasing air service to and within the country. Maoist conflict, 1996–2006
2000	Significant decline in tourism due to Maoist conflict, 1996–2006 Additional conservation polices placing strong restrictions on local energy use, timber use, and agriculture 35,000+ tourists visit the region	Pharak gazetted as buffer zone, 2002	311 lodges in Sagarmatha National Park and Buffer Zone, 2012	Following a World Bank structural adjustment program, 2000. Nepal's government lifted a monopoly on domestic airline service and numerous private carriers began providing expanded air service capacity throughout the country.

distribution of each LULC type for 1992 to 2011 in order to address overall LULC change, as well as for 2 time steps within this period (1992–2000 and 2000–2006) to detect changing trends. In addition, a cross-tabulation matrix was generated from the ICIMOD data sets (Pontius and Cheuck 2008). This allowed the calculation of relative percentage changes for each LULC class and time step, in this case for 1992–2000 and 2000–2006. A schematic diagram of the geographic information system (GIS) process employed for analysis is presented in the

Supplemental material, Figure S1; (http://dx.doi.org/10.1659/MRD-JOURNAL-D-15-00005.S1). A further field mission was carried out in September 2011 for validation of the LULC trends.

Step 3 was the assessment of classification accuracy. A uniform grid of 500 × 500 m was generated over the area, and 20% of these points were selected randomly and used for accuracy assessment. The LULC at each point was interpreted with the help of IKONOS-2 4-m Multispectral and RapidEye images and field photographs. Additional data from ground control points were also used for validation. These were then compared with the LULC maps to calculate the error matrix. Interpretation accuracy for the ICIMOD data sets varied from 95.1 to 96.8%; the LULC classes adopted by the Nepal Government Department of Survey provided interpretation accuracies of 94.7 to 97.9% (*Supplemental material*, Tables S5–S10: http://dx.doi.org/10.1659/MRD-JOURNAL-D-15-00005.S1). Key factors influencing the interpretability of the data were the season when the image was obtained, the complexity of the terrain, the slope, and its aspect. Discrepancies between the different data sets and classification systems highlight the challenges inherent in analyzing LULC change in mountain regions (Gautam and Watanabe 2004), which is why field verification, particularly visual analysis, as well as local knowledge, considerably improved the results obtained.

Interviews and workshops

Field interviews were conducted in the 6 villages inhabited year-round to elicit local people's perceptions of the causes and consequences of LULC change within SNPBZ. A total of 56 local people were interviewed during 2009–2011 using photo-elicitation during semistructured interviews (see Garrard et al 2012a for a summary of the qualitative research method).

Workshops were held in the same villages. The aim was to generate representative data according to gender, age, and economic status (Garrard et al 2012a). Purposive sampling resulted in a total of 69 workshop participants across all villages (female = 38; male = 31). Participants were told that the objective of the workshop was to explore LULC change. They were asked to list the LULC changes they had observed over the last few decades, and could list as many changes as they wanted. The responses were then ranked according to the total number of participants who mentioned each change, and summed for all villages. The assumption was made that a participant's first response would be the change he or she considered most significant.

Participants were also asked to list the drivers of the changes they had mentioned; their spatial origin; whether the changes were local, national, or global; and whether the temporal changes were short-term, midterm, or long-term. The scores for each driver were also summed. We incorporated some of this information into a GIS database to produce 6 high-resolution (1:5000–1:25,000) land-use field maps. Key informants were selected through a snowball sample to interpret remotely sensed data. They provided critical in-depth LULC change information, particularly about the impact of drivers and their spatial and temporal effects.

Results and discussion

LULC change 1992–2011

Results are presented for LULC change for the period 1992–2011 and for 2 time steps within that period, 1992–2000 and 2000–2006. The foremost change over the longer period was a decrease in snow and ice cover by 160.21 km^2 or 43%. At the same time, glacial lakes and areas covered by rock and soil expanded (Table 1). These results are consistent with previous land cover analysis in SNPBZ (eg Bajracharya et al 2010; Yong et al 2010), and in the Himalaya in general (Bolch et al 2012). As there are few human activities above 6000 m (except climbing), increasing temperature is likely to be the most important driver of these changes. Snow and ice decayed more rapidly in 2000–2011 than in 1992–2000.

To explore LULC change in relation to land-use strategies, Table 2 focuses on productive land classes (excluding rock, lakes, and glaciers). The total area of these classes showed a slow but continuous decline in 1992–2011, from 421 to 376 km^2 (an 11% decrease). Shrubland and particularly forests decreased over this period (26.27 km^2), whereas grazing and agriculture remained relatively constant. Settlement areas had the smallest change in total area, from 0.29 km^2 in 1992 to 1.02 km^2 in 2011, but this was an increase of over 250%. This increase had a high impact on resource use near settlements, in conjunction with the effects of tourism.

LULC change 1992–2000

In the first time period (1992–2000), the decrease in forests (by 6.23 km^2 or 0.83%) and shrublands is already clearly visible (Table 2), and grazing area and agricultural land increased. Workshop participants indicated that these changes were directly related to increased use of cattle (Sherpa and Kayastha 2009), especially male crossbred cattle (eg *zopkio*), which are the livestock of choice as pack animals for tourism. Certain shrubs—for example juniper (*Juniperus recurva* and *J. wallichiana*) and rhododendron (*Rhododendron campanulatum* and *R. arboreum*)—were also used for heating. Workshop participants also confirmed that the decrease of forests was mainly due to the use of timber for heating and construction for local needs and tourism.

Most workshop participants (84%) stated that the increase in agricultural area represented a change to cash crop farming (primarily of potatoes) in and around the main villages (at 3400–3800 m elevation) and on land

TABLE 1 Land use and land cover change, 1992–2011.[a)]

LULC	1992		2000		2006		2011		Change (km^2)
	km^2	%	km^2	%	km^2	%	km^2	%	
Productive land classes									
Agriculture	9.92	0.70	10.27	0.73	8.88	0.63	8.50	0.60	–1.42
Forest	110.27	7.81	104.04	7.36	97.07	6.87	84.00	5.94	–26.27
Grazing	71.20	5.04	78.90	5.58	67.76	4.79	69.24	4.90	–1.96
Settlement	0.29	0.02	0.25	0.02	0.76	0.05	1.02	0.07	0.73
Shrubland	230.29	16.32	217.75	15.48	216.17	15.37	213.40	15.09	–16.89
Other land classes									
Lake	5.77	0.41	8.56	0.61	8.42	0.60	9.29	0.66	4.15
Bare rock/soil	614.45	43.54	683.85	48.39	792.27	56.34	817.90	57.85	203.45
Permanent ice	370.81	26.16	309.49	21.83	222.61	15.35	210.60	14.89	–160.21
All land classes									
Total	**1413.00**	**100.00**	**1413.11**	**100.00**	**1413.94**	**100.00**	**1413.95**	**100.00**	

a) Percentages refer to percentage of total land area.

adjacent to permanent water sources. In contrast, distant high-elevation (4000–4200 m) agricultural sites were abandoned as people turned increasingly to tourism as a livelihood. For example, in the Thame Valley, 0.41 km^2 (0.11%) of agricultural land was abandoned between 1992 and 2000 (Figure 3). For the same area, we were able to spatially map the extent of abandoned agricultural land over time by having participants draw direction lines (black arrow) and area polygons on the satellite images presented in the workshops, which were color coded and digitized in ArcGIS. Figure 3 shows the general direction of abandonment from more remote and higher areas to places closer to settlements, a trend that continued after 2000. Study participants also pointed out that abandonment of smaller agricultural areas also occurred before 1990 in the Thame Valley, triggered by natural hazards such as the devastating 1985 glacial lake outburst flood.

The most conspicuous change in land cover classes for the SNPBZ as a whole between 1992 and 2000 (Table 3) is that 11% of the snow/ice area changed into soil and bare rock. The same percentage of rock and bare soil turned into shrub- and grasslands. Both changes may point to a habitat succession, with shrubs and grass shifting to higher elevations, fueled by the increasing temperatures in the southern Himalaya since the 1970s (eg Diodato et al 2011). Workshop participants confirmed these trends and said that glacial moraines were widening because of the breakdown of association between rock, soil, and ice. Glaciers are collapsing and depositing debris consisting of bare soil and rock. The reduction in snow and ice cover exposes rocks and soil in the higher elevations, with the possibility of increasing the size of glacial lakes (Bolch et al 2012).

A substantial part of the forested area changed into shrub- and grassland, but not all forest types experienced

TABLE 2 Change in productive land categories, 1992–2011.[a)]

Land use	1992		2000		2006		2011	
	km^2	%	km^2	%	km^2	%	km^2	%
Agriculture	9.92	2.35	10.27	2.50	8.8	2.34	8.50	2.26
Forest	110.27	26.14	104.04	25.30	97.07	24.84	84.00	22.33
Grazing	71.2	16.87	78.9	19.19	67.06	17.20	69.24	18.41
Settlement	0.29	0.07	0.25	0.06	0.76	0.19	1.02	0.27
Shrubland	230.29	54.57	217.75	52.95	216.17	55.45	213.40	56.73
Total	421.97	100.00	411.21	100.00	389.86	100.00	376.16	100.00

a) Percentages refer to percentage of productive land area.

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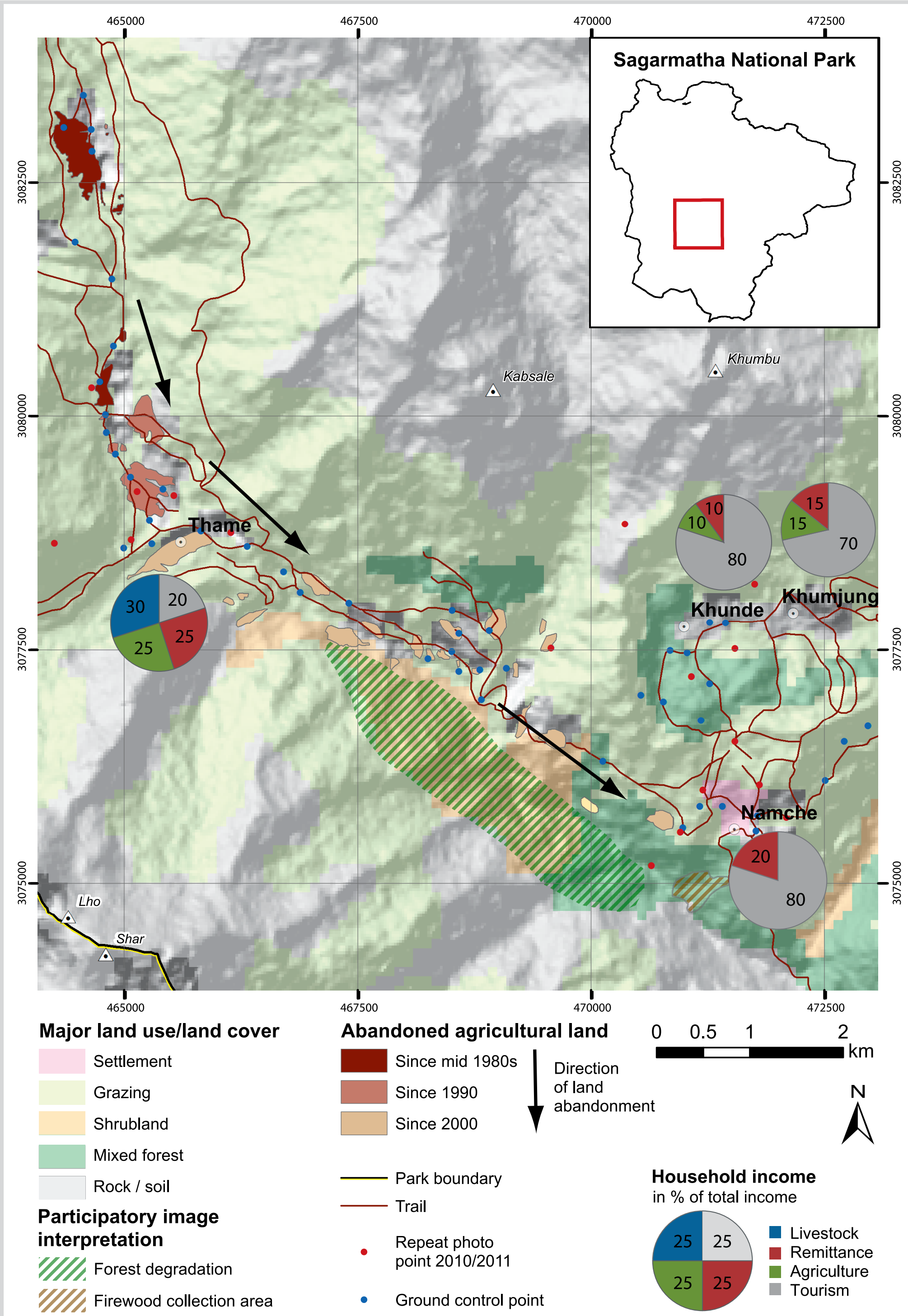
FIGURE 3 Changes in land use strategies in Thame Valley. (Map by Elias Hodel and Rodney Garrard; household data from Sherpa and Kayastha 2009)



similar rates of change (16.7% for needle forests; 18.19% for mixed forests, and 20.05% for broadleaved forests). These findings are consistent with those of Bajracharya et al (2010), except that the latter analysis showed a greater decrease in broadleaf forest (>25%), probably owing to a lack of field verification and extrapolation of this land cover class in shadow areas. When discussing this LULC change, 77% of workshop participants said the main drivers were increased demand for timber for new lodges and fuelwood in more accessible areas and intensified agriculture of riparian

TABLE 3 Change matrix for land cover classes, 1992–2000. Numbers indicate percentage of total land cover.[a)]

Land cover	1992–2000							
	Rock/ soil	Snow/ glacier	Glacial lake	Shrub/ grass	Agriculture/ settlements	Needle forest	Mixed forest	Broadleaved forest
Rock/soil	85.32	2.89	0.28	**11.21**	0.08	0.04	0.08	0.10
Snow/glacier	**10.89**	88.28	0.55	0.28	0.00	0.00	0.00	0.00
Glacial lake	**5.52**	4.81	88.80	1.25	0.04	0.00	0.00	0.00
Shrub/grass	**18.23**	0.14	0.04	78.04	**0.20**	1.43	1.34	0.58
Agriculture/ settlements	2.99	0.01	0.00	3.23	92.53	0.51	0.16	0.57
Needle forest	3.34	0.00	0.00	**16.74**	0.00	65.10	10.11	4.71
Mixed forest	8.79	0.03	0.00	**18.19**	0.14	**4.07**	63.01	5.77
Broadleaved forest	3.16	0.00	0.00	**20.05**	0.38	6.63	**13.12**	56.66

[a)] Grayed cells show the percentage of a given land cover that did not change; bold figures show significant changes.

zones close to settlements. Areas covered by shrublands (eg juniper and rhododendron) were converted to rock and soil at a disturbing rate (18.23%). When discussing this change, 77% of workshop participants blamed increased grazing and increased demand for fuelwood in higher-elevation areas where no wood is available.

LULC change 2000–2011

In the second time period (2000–2011), land cover change accelerated, especially relating to snow and ice, which lost about 100 km^2, compared to 61 km^2 in the decade before. The area of bare rock and soil increased by 134 km^2, compared to 70 km^2 in the previous decade (Table 1). The decrease in agriculture and grazing from 2000–2006 in particular is a direct result of a drop in tourism during the Maoist conflict in the late 1990s and early 2000s (Figure 2), according to workshop findings. The fluctuation in numbers of tourists visiting SNPBZ makes a huge difference to local livelihoods, and the local people were very concerned about this variation. Overall, 79% of workshop respondents highlighted the lack of park management during the conflict, which led to a greater exploitation of forest resources, especially near the main villages and trekking trails. Forest area continued to decrease in 2006–2011. Building and construction appear to have continued unabated in spite of the Maoist insurgence, showing a 4-fold growth in area cover during 2000–2011.

Although the loss of agricultural area in the whole of the study area stopped after 2006, abandonment continued in parts of the region, such as the Thame Valley. This valley has been only marginally exposed to tourism, a fact clearly reflected in local livelihoods, which differ markedly from those of the tourism centers around Namche. In Thame, 0.46 km^2 (0.13%) of agricultural land was abandoned in 2000–2011 (Figure 3). Although the percentage change of abandoned agricultural land is small, the change is significant given the total available agricultural land, and focuses LULC change processes at the appropriate spatial scale. For example, 81% of workshop participants saw land abandonment as a significant land use change, and referred to similar trends in the 2 other valleys of SNPBZ (Figure 1). The abandonment of agricultural land in the Thame Valley has also coincided with general depopulation in the area since 2001 (*Supplemental material*, Table S3; http://dx.doi.org/10.1659/MRD-JOURNAL-D-15-00005.S1). Abandonment of agricultural land is a trend found in many mountain regions worldwide (Khanal and Watanabe 2006), mainly because of male outmigration. However, the Khumbu is a special case, as tourism provides a viable and lucrative local alternative to farming. Workshop participants outlined that tourism was about to eclipse farming, and that the region had in fact developed into a monoculture tourism economy. In 2009, over 80% of household income in Namche came from tourism and 20% from remittances (Sherpa and Kayastha 2009; Figure 3), and it was the landowners from Namche who were largely responsible for land abandonment in the Thame Valley.

During 2000–2006 (Table 4), the change of snow and glacier into bare rock and soil (15.43%) was greater than in the 1990s. These land cover classes are generally interrelated; the melting of snow and ice exposes more rocks and soil and creates more glacial lakes. Thakuri et al (2013) reported a mean annual warming of 0.3°C in SNPBZ from 1992 to 2012; however, it may be premature to determine a climate trend. Such results are also consistent with Yong et al (2010), who observed glaciers retreating and glacier lakes expanding across SNPBZ from 1992–2006.

In the productive land classes, the conversion of all types of forest into shrub, and of grassland to bare rock and soil, continued at even greater levels in the latter time period (Table 4). Deforestation has occurred at these rates in spite of the high levels of protection imposed by park managers and by local communities. The reasons advanced by the

TABLE 4 Change matrix for land cover classes, 2000–2006. Numbers indicate percentage of total land cover.

Land cover	2000–2006							
	Rock/ soil	Snow/ glacier	Glacial lake	Shrub/ grass	Agriculture/ settlements	Needle forest	Mixed forest	Broadleaved forest
Rock/soil	85.74	1.85	0.12	**11.93**	0.10	0.13	0.05	0.08
Snow/glacier	**15.43**	83.50	0.16	0.91	0.00	0.00	0.00	0.00
Glacial lake	**11.94**	11.47	73.97	2.62	0.00	0.00	0.00	0.00
Shrub/grass	**20.95**	0.27	0.04	76.41	0.19	0.73	0.35	1.06
Agriculture/ settlements	3.04	0.27	0.18	**14.59**	80.30	1.29	0.88	1.44
Needle forest	0.51	0.00	0.00	**20.89**	**0.26**	72.81	2.03	3.50
Mixed forest	0.86	0.00	0.00	**23.83**	0.21	**6.32**	54.46	14.32
Broadleaved forest	1.17	0.00	0.00	**21.24**	0.30	7.41	**7.66**	62.22

[a] Grayed cells show the percentage of a given land cover that did not change; bold figures show significant changes.

workshop participants correspond to those for the earlier time period. The invasion of shrub- and grassland on recently denuded areas (rock and soil) at higher elevations was confirmed in the workshops. This may suggest an upward movement of vegetation due to increasing temperatures, an observation consistent with results obtained in other mountain regions (Körner and Ohsawa 2005).

LULC change and its drivers as seen by local residents

Local perceptions of LULC change are summarized in Table 5. Participants identified the major LULC changes as increasing commercialization of agriculture, forest degradation (especially due to grazing), abandonment of agricultural land, deforestation and overharvesting of forest products, and the appearance of shrub- and grassland on soil that had previously been covered by snow and ice. Slightly fewer than half of participants perceived loss of snow and glacier area as an LULC change, a marked contrast to the results of satellite image analysis. The same proportion of participants mentioned increasing settlement size, which satellite image analysis identified as a minor LULC change category. Increasing crop failure was perceived by only 21% of the respondents as a major LULC change.

Participants were also asked about their perceptions of the forces driving LULC change (Table 6). Each driver was further discussed in terms of whether it was anthropogenic or natural, whether it was local and could be controlled through local management or originated outside of SNPBZ, and whether it had a short- or longer-term effects on ecosystems and livelihoods. Participants identified 3 main drivers: park management, tourism development, and, to a lesser degree, climate and weather.

Lack of park management was seen as a major driver of LULC changes. Many respondents said that there was a failure to enforce park rules during the height of the Maoist conflict, resulting in overexploitation of forests for fuelwood and timber by local residents and the armed

TABLE 5 Workshop participants' perceptions of major LULC change. Participants were allowed to choose as many responses as they wanted.

Perceived LULC change	Chosen by participants		Total score
	Number of participants	% of participants	
Increasing cash cropping	58	84	147
Forest degradation	57	82	136
Land abandonment	56	81	137
Deforestation/overharvesting	51	73	120
Appearance of shrub at higher elevations	39	56	74
Less snow in mountains/glacial retreat	33	46	81
Increase in settlement size and population	30	46	75
Increasing crop failure	15	21	42

TABLE 6 Workshop participants' perceptions of key forces driving LULC change and the spatial and temporal scale of their effects. Participants were allowed to choose as many responses as they wanted.[a)]

Driver	Chosen by participants		Total score	Origin (anthropogenic versus natural)	Origin (local, national or global)	Effect (short-term, midterm or long-term)
	Number	%				
Lack of park management	55	79	141	Anthropogenic	Local/national	Short-term
Increased grazing	54	78	146	Anthropogenic	Local	Short-midterm
Increased timber use	53	77	134	Anthropogenic	Local	Short-midterm
Rapid tourism development	46	65	147	Anthropogenic	Global	Short-term
Ineffective park management	41	58	115	Anthropogenic	Local/national	Short-midterm
Climate variability/unpredictable weather	32	46	105	Natural	National/global	Long-term
No restriction of grazing	30	43	69	Anthropogenic	Local	Short-term
Increased number of cattle	26	38	74	Anthropogenic	Local	Short-term
Political instability	15	22	87	Anthropogenic	National	Short-midterm

[a)] "Lack of park management" refers to the era of the civil war; "ineffective park management" is a more general comment; "increased grazing" refers primarily to *zopkio*; "increased timber use" refers primarily to lodge building.

forces stationed in the region. Closer inspection of the remotely sensed datasets indeed revealed spatially concentrated forest loss during the conflict years. Many participants also saw park management as more generally ineffective (not just during the Maoist conflict). They said that it is difficult to create a lasting partnership between park management and the local community as park wardens change frequently.

Rapid tourism development relates to the growth of settlements. According to participants, the number of hotels and lodges is not sufficient during the peak tourist season. This has resulted in a lodge construction boom, with property and lands adjacent to the main trekking trails soaring in economic value.

Grazing pressure and increased timber use were seen by participants as linked to the tourism boom and to issues in park management. Participants said that grazing pressure has increased, especially for *zopkio*, which are pack animals heavily used in tourism. They also mentioned increased harvesting of timber for lodge construction and for heating these facilities. Although park management does allow the harvesting of firewood on a rotational basis and provides a few trees to build new houses and renovate old ones, local people, however, stated that park management allows uncontrolled harvesting of forest products, and exerts little or no control over livestock grazing and herd size.

Climate variability—the way climate fluctuates yearly—rather than climate change, a long-term continuous change to weather conditions, is the only nonanthropogenic driver identified by participants and was mentioned by fewer than half of them. This is in line with their relatively infrequent mention of snow and glacier retreat and crop failures as LULC changes.

In sum, participants' perceptions of LULC change tended to concentrate on shifts in agriculture and forest use rather than on the gradual but continuous change in snow and ice apparent in the satellite imagery. This latter change is perhaps more susceptible to a "shifting baseline syndrome" (eg Pauly 1995), in which observers may not notice gradual changes. On the other hand, many of the LULC changes observed by local community members are occurring at fine spatial scales that satellite imagery is not able to access. This underscores the importance of triangulation and reconciliation of findings obtained from different research approaches (Jurt et al 2015).

The drivers of LULC change identified by study participants are overwhelmingly local, or more precisely, local responses to national and global developments such as the growth of tourism, and directly related to local livelihoods (Figure 2). These drivers could be controlled through improved park management, especially if addressed in collaboration with the local population. Other drivers originate from outside SNPBZ. These include lack of park management during the civil war, which underscores the vulnerability of protected areas and the spatial dynamics of forest resource dependence during conflicts and political instability. The effects of such external factors on LULC change are not well understood, but they often have a strong impact on both protected-area management and local livelihoods (eg Verburg et al 2006; Galvin and Haller 2008).

Conclusion

LULC change analysis can greatly benefit from a mix of satellite image analysis and input from local residents. Satellite images show that the decrease in area covered by

snow and ice is by far the most extensive land cover change in SNPBZ. Climate change is the likely driver of this change, and mitigating against the effects of climate change is largely beyond the scope of local development and conservation efforts. In contrast, study participants assigned the most weight to changes directly linked to their livelihoods. In their eyes, key changes include intensification of farming around growing settlements, associated with increasing pressure on natural resources such as forests and grazing lands, and abandonment of more remote farmland. They see these changes as driven by the tourism boom and by inefficient park management. Climate variability (climate change was not explicitly stated by study participants) was much less often mentioned than one would expect based on the satellite imagery. However, as climate change continues, glacial retreat may affect land use strategies and local livelihoods to a greater extent; for example, the loss of snow and ice might impact tourism. Local people also have a different set of concerns than most of the current NGO-led research programs, which focus on glacier retreat (eg Sherpa 2014; Garrard and Carey 2016).

When analyzing remotely sensed data, collecting field data for reference and validation is both vital and challenging, especially in mountain regions, because of the rough terrain, remoteness, access problems, and frequent cloud cover. Consistency of definitions of LULC classes is another challenge, especially when working with data sets collected by different institutions over time. In this study, combining satellite image analysis with local ethnographic and geospatial research enabled us to elucidate different aspects of LULC change and identify fine-grained LULC change trajectories. The participatory mapping exercise yielded further insights into the abandonment of high-elevation agricultural areas in favor of increased off-farm work in the tourism industry. This change could affect local food security and increase the risk of erosion and landslides.

Local residents' perception that increasing tourism, ineffective park management, and consequent pressure on natural resources are key drivers of LULC change in SNPBZ presents a challenge for the park authorities. The challenge for park authorities lies in the twin tasks of nature conservation and the creation of an environment conducive to economic development, including tourism. Excessive tourism development and overuse of local resources may undermine the goals of the park's UNESCO World Heritage status and could threaten this status altogether. Whether and how this would affect tourism is another question. In addition, tourism is increasingly seen as an asset rather than a threat in the current World Heritage concept. Given the projected increase in tourism within the SNPBZ, it is likely that the LULC change identified in this paper will intensify in future.

Worldwide, 17% of mountain areas are under some kind of protection (IUCN 2010). Many of these, including the Khumbu, were settled before this protection was established. A contextual analysis of LULC change as presented in this paper can help support protected area management without alienating local people—who, most scholars agree, should increasingly take ownership of decision-making (Conradin and Wiesmann 2014). Although much of the LULC change in SNPBZ is in the realm of nonproductive land and is affected by global factors that cannot be mitigated or influenced locally, many of the local drivers of LULC change identified in this paper—ineffective park management, insufficient limits on forest use, overgrazing, and rapid tourism development—can be addressed concretely by improved management in the park and by regional development planning involving stakeholders. The kind of integrated information presented in this paper is critical if we are to improve park management and regional planning for development. An LULC change analysis including context, drivers, and time scales is thus useful for agenda setting, addressing issues, and guiding discussions with the aim of promoting local nature conservation and sustainable mountain development as well as contributing to policy formulation at national and global levels.

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REFERENCES

Bajracharya B, Uddin K, Chettri N, Shrestha B, Siddiqui AS. 2010. Understanding land cover change using a harmonized classification system in the Himalayas: A case study from Sagarmatha National Park, Nepal. *Mountain Research and Development* 30(2):143–156.

Bolch T, Kulkarni A, Kääb A, Huggel C, Paul F, Cogley JG, Frey H, Kargel JS, Fujita K, Scheel M, Bajracharya S, Stoffel M. 2012. The state and fate of Himalayan glaciers. *Science* 366:310–314.

Central Bureau of Statistics. 2012. *National Population and Housing Census 2011 (National Report)*. Vol 1. Kathmandu, Nepal: Government of Nepal National Planning Commission Secretariat Central Bureau of Statistics. http://cbs.gov.np/wp-content/uploads/2012/11/National%20Report.pdf; accessed on 1 August 2014.

Chaudhary RP, Aase TH, Vetaas OR, Subbedi BP, editors. 2007. *Local Effects of Global Changes in the Himalayas: Manang, Nepal*. Kathmandu, Nepal: Tribhuvan University; Bergen, Norway: University of Bergen.

Conradin C, Wiesmann U. 2014. Does World Heritage status trigger sustainable regional development efforts? *eco.mont* 6(2):5–11.

Couzin J. 2007. Opening doors to native knowledge. *Science* 315:1518–1519.

Diodato N, Bellocchi G, Tartari G. 2011. How do Himalayan areas respond to global warming? *International Journal of Climatology* 32:975–982.

Ev-K2-CNR. 2012. *Data Provided Within the Framework of the Ev-K2-CNR/NAST Joint Project as Foreseen by the Memorandum of Understanding between Nepal and Italy*. Bergamo, Italy: Comitato Ev-K2-CNR.
Galvin M, Haller T, editors. 2008. *People, Protected Areas and Global Change: Participatory Conservation in Latin America, Africa, Asia and Europe*. Perspectives of the Swiss National Centre of Competence in Research (NCCR) North-South, University of Bern, Vol. 3. Bern, Switzerland: Geographica Bernensia.
Garrard R, Carey M. 2017. Beyond images of melting ice: Hidden stories of people, place, and time in repeat photography of glaciers. *In:* Bear J, Albers KP, editors. *Before-and-After Photography: Histories and Contexts*. New York, NY: Bloomsbury Academia.
Garrard R, Kohler T, Wiesmann U, Price FM, Byers CA, Sherpa AR. 2012a. Depicting community perspectives: Repeat photography and participatory research as tools for assessing environmental services in Sagarmatha National Park, Nepal. *eco.mont* 4(2):21–31.
Garrard R, Kohler T, Wiesmann U, Price FM, Byers CA, Sherpa AR. 2012b. An Ever-changing place: Interpreting landscape change in Sagarmatha (Mt Everest) National Park, Nepal: Re-photographic survey and encounter. *eco.mont* 4(2):49–55.
Gautam CM, Watanabe T. 2004. Reliability of land use/land cover assessment in montane Nepal: A case study in the Kangchejunga Conservation Area (KCA). *Mountain Research and Development* 24(1):35–43.
Gehrig R. 2013. *Lodge Development in Khumbu, Nepal* [MSc thesis]. Bern, Switzerland: Center for Development and Environment, University of Bern.
ICIMOD [International Centre for Integrated Mountain Development]. 2009. *Decision Support Toolbox CD/User Manual*. Kathmandu, Nepal: Hindu Kush–Karakoram–Himalaya Partnership Project.
IUCN [International Union for Conservation of Nature]. 2010. *The World Database on Protected Areas (WDPA): January 2010*. Cambridge, United Kingdom: United Nations Environment Programme's World Conservation Monitoring Centre.
Ives JD. 2004. *Himalayan Perceptions: Environmental Change and the Well-Being of Mountain Peoples*. Abingdon, United Kingdom: Routledge.
Jurt C, Burga DM, Vicuna L, Huggel C, Orlove B. 2015. Local perceptions in climate change debates: Insights from case studies in the Alps and the Andes. *Climatic Change* 133(3):511–523.
Kennedy RE, Townsend PA, Gross JE, Cohen W, Bolstad P, Wang YQ, Adams P. 2009. Remote sensing change detection tools for natural resource managers. Understanding concepts and trade-offs in the design of landscape monitoring projects. *Remote Sensing and Environment* 113:1382–1396.
Khanal RN, Watanabe T. 2006. Abandonment of agricultural land and its consequences. A case study in the Sikles area, Gandaki Basin, Nepal. *Mountain Research and Development* 26(1):32–40.
Kohler T, Pratt J, Debarbieux B, Balsiger J, Rudaz G, Maselli D, editors. 2012. *Sustainable Mountain Development, Green Economy and Institutions. From Rio 1992 and Beyond*. Bern, Switzerland: Swiss Agency for Development and Cooperation.
Körner C, Ohsawa M, editors. 2005. Mountain systems. *In: Ecosystems and Human Well-Being: Current State and Trends*. Vol 1. Washington, DC: Island Press, pp 681–716.
Lambin EF, Meyfroidt P. 2010. Land use transitions: Socio-ecological feedback versus socio-economic change. *Land Use Policy* 27:108–118.
Lambin EF, Meyfroidt P. 2011. Global land use change, economic globalization, and the looming land scarcity. *Proceedings of the National Academy of Sciences of the United States of America* 108(9):3465–3472.
LRMP [Land Resource Mapping Project]. 1986. *Land Utilization Report*. Governments of Nepal and Canada. Ottawa, Canada: Kenting Earth Sciences Limited.
Mattle B. 1999. *Räumliche und zeitliche Entwicklung der touristichen Infrastructur in Khumbu, Nepal* [Diploma thesis]. Bern, Switzerland: University of Bern.
Nüsser M, Gerwin M. 2008. Diversity, complexity and dynamics: Land use patterns in the central Himalayas of Kumaon, Northern India. *In:* Löffler J, Stadelbauer J, editors. *Diversity in Mountain Systems*. Colloquium Geographicum 31. St. Augustin, Germany: Asgard-Verlag, pp 107–119.
Pauly D. 1995. Anecdotes and shifting baseline syndrome of fisheries. *Trends in Ecology and Evolution* 10:430.
Pontius RG, Cheuck ML. 2008. A generalized cross tabulating matrix to compare soft classified maps at resolution. *International Journal of Geographical Information Science* 20(1):1–30.
Sherpa P. 2014. Climate change, perceptions, and social heterogeneity in Pharak, Mount Everest region of Nepal. *Human Organization* 73(2):153–161.
Sherpa YD, Kayastha BR. 2009. A study of livestock management patterns in Sagarmatha National Park: Trends affected by socioeconomic factors and climate change. *Kathmandu University Journal of Science, Engineering and Technology* 5(2):110–120.
Stevens SF. 1996. *Claiming the High Ground. Sherpas, Subsistence, and Environmental Change in the Highest Himalaya*. Oakland, CA: University of California Press.
Stevens SF. 2013. National parks and ICCAs in the high Himalayan region of Nepal: Challenges and opportunities. *Conservation and Society* 11:29–45.
Thakuri S, Salerno F, Guyennon N, Viviano G, Smiraglia C, D'Agata C, Tartari G. 2013. Glacier response to climate trend and climate variability in Mt. Everest region (Nepal). Poster presented at the *2013 American Geophysical Meeting*, Cancun, Mexico. http://moa.agu.org/2013/eposters/eposter/c21b-01/; accessed on 20 August 2016.
Vedwan N, Rhoades RE. 2001. Climate change in the Western Himalayas of India: A study of local perception and response. *Climate Research* 19:109–117.
Verburg PH, Overmars KP, Huigen MG, de Grot WT, Veldkamp A. 2006. Analysis of the effects of land use changes on protected areas in the Philippines. *Applied Geography* 26(2):153–173.
Yong N, Yili Z, Linshan L, Jiping Z. 2010. Glacial change in the vicinity of Mt. Qomolangma (Everest), central high Himalayas since 1976. *Journal of Geographic Sciences* 20(5):667–686.

Supplemental material

FIGURE S1 GIS method and process employed in the study. Land use was not mapped for the year 2000.
TABLE S1 Population of the Khumbu region, 1957–2011.
TABLE S2 Population of each village that is inhabited year-round, 1978–2011.
TABLE S3 Land use and land cover categories used by ICIMOD and DNPWC as part of the LRMP.
TABLE S4 Satellite images and geographic data used in this study.
TABLE S5 Results of assessment of land use classification accuracy, Nepal Government Department of Survey (LRMP 1986), 2011. Overall classification accuracy was 97.9%.
TABLE S6 Results of assessment of land use classification accuracy, Nepal Government Department of Survey (LRMP 1986), 2006. Overall classification accuracy was 96.8%.
TABLE S7 Results of assessment of land use classification accuracy, Nepal Government Department of Survey (LRMP 1986), 1992. Overall classification accuracy was 94.7%.
TABLE S8 Results of assessment of land cover classification accuracy, ICIMOD data sets, 2006. Overall classification accuracy was 96.8%.
TABLE S9 Results of assessment of land cover classification accuracy, ICIMOD data sets, 2000. Overall classification accuracy was 95.9%.
TABLE S10 Results of assessment of land cover classification accuracy, ICIMOD data sets, 1992. Overall classification accuracy was 95.1%.

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